ABSTRACT

Road access can influence protective and risk factors associated with nutrition by affecting various social and biological processes. In northern coastal Ecuador the construction of new roads created a remoteness gradient among villages, providing a unique opportunity to examine the impact of roads on child nutritional outcomes 12 years after the road was built. Anthropometric and hemoglobin measurements were collected from 2,350 children < 5 years in Esmeraldas, Ecuador from 2004–2013 across 28 villages with differing road access. Logistic generalized estimating equation models assessed the longitudinal association between village remoteness and prevalence of stunting, wasting, underweight, overweight, obesity, and anemia. We examined the influence of socioeconomic characteristics on the pathway between remoteness and nutrition by comparing model results with and without household level socioeconomic covariates. Although remoteness was statistically significantly associated with stunting (OR=0.43, 95% CI=0.30, 0.63) and anemia (OR = 0.56, 95% CI=0.44, 0.70), the prevalence of stunting was generally decreasing but remained higher in close-by than in far villages. Obesity increased (0.5% to 3%) over time; wasting was high (6%) but stable during the study period. Communities residing in more remote regions had better nutritional outcomes compared to those communities living close to a road. Wealth and education partially explained these associations. Establishing the extent to which these patterns persist requires additional years of observation. Our observations thus far suggest that road access has negatively influenced the nutritional status of children in this region of Ecuador, more than a decade after some communities gained road access.

Keywords: child malnutrition; distal determinant; roads; child nutrition; global health; anthropometry

INTRODUCTION

Malnutrition among children under five is a general indicator of ill health in a population (Onis et al., 2000). An estimated 45 percent of all deaths among children under five are attributed to undernutrition (Black et al., 2013). The burden of undernutrition is amplified because frequent infections in children increase the risk of undernutrition, and undernutrition increases the risk of infection, creating a vicious circle in areas where access to food and healthcare is poor (Scrimshaw, 2003). On the other hand, overweight and obese children have many of the comorbidities plaguing overweight and obese adults, such as elevated blood pressure, dyslipidemia, or other risk factors common to type 2 diabetes (Deckelbaum et al., 2001). Increasingly, both undernutrition and overweight/obesity outcomes have been concurrently observed throughout low- and middle-income (LMI) populations (Kennedy et al., 2006; Varela-Silva et al., 2012).

Food systems, specifically food availability and consumption, which in turn affect population nutrition, are influenced by macro-level factors, such as globalization (Popkin, 2006). In the context of our study, availability and consumption of food may be influenced by a critical component of globalization called differential road access, which creates a gradient of remoteness. We collected anthropometric data in children over a ten-year period in northern coastal Ecuador. We hypothesize that differential road access in this population is a key driver of sociodemographic changes that influence nutritional outcomes in children under five. Specifically, we assessed four undernutrition outcomes: stunting, wasting, underweight, and anemia; as well as overweight and obesity.

These childhood undernutrition outcomes have important distal sociodemographic determinants at the individual-level (e.g., age), at the household-level (e.g., household wealth, number of siblings, family employment, and education of the mother (Larrea et al., 2005; Victora et al., 1986)), as well as at the community-level (e.g., differences in food security, access to healthcare, and organized sanitation between communities (Khan et al., 2010)). These distal determinants can in turn be altered by road access. Roads promote easier movement of people, food, and services, and may lead to regional economic improvement that would presumably improve nutritional outcomes through multidimensional pathways (Hine et al., 2014) including the normalization of marketplace exchanges (Hawkes, 2006). Living in an urban community has been shown to impact undernutrition through a decreased risk of stunting compared to living in rural communities (Kandala et al., 2011; Ortiz et al., 2014). However, roads can also potentially have negative consequences. For example, our studies have shown that less remote communities have a higher prevalence of diarrheal disease (Eisenberg et al., 2006). This finding may be due, in part, to the fewer social contacts among individuals living in less remote villages, who also have higher migration and movement rates (Trostle et al., 2008) and, counter to generally accepted views, this lower social network density enhances their risk of diarrhea (Bates et al., 2007). In the context of infection transmission, network ties are thought to solely represent conduits of transmission; however, they can also represent levels of social cohesion (Entwisle et al., 2007). Network density, therefore, is also likely a marker of individual-level as well as collective community-level water, sanitation, and hygiene related-practices that mediate the relationship between remoteness and disease prevalence (Zelner et al., 2012). These dynamics influence the distal determinants of health in complex ways.

Here, we examine whether road access, in addition to influencing community-level interactions and infection, can also influence community-level outcomes of nutritional status. Identifying nutritional risk factors present in different environments over time may help elucidate how nutrition outcomes change within a population and can help to inform interventions to protect those vulnerable to poor nutrition. The construction of a road in a previously roadless region of northern coastal Ecuador provides a unique opportunity to study how a village's remoteness profile maps onto temporal trends in childhood nutrition.

In this study, we report village-level nutritional trends among children under five years of age in Esmeraldas Province to determine how these trends vary by time and place. Guided by a conceptual model akin to a neighborhood-level analysis, we view road access as influencing nutrition through its effect on community-level measures (e.g. wealth, education, and family size), and analyze nutritional data gathered over ten years across nine timepoints and 28 villages of varying remoteness levels. Changes brought about by road construction may lead to improved nutrition; however, road access can also introduce processed food and poor sanitation to the region, increasing the long-term risk of both undernutrition and overweight and obesity outcomes. The purpose of the present study is to determine the role of village remoteness on nutrition outcomes over time.

METHODS

Setting

The province of Esmeraldas, located along the northern coast of Ecuador, is home to a large Afro-Ecuadorian population. In 1996 a national road construction project to link Colombia and Ecuador began, and in 2001 a two-lane paved highway was completed in the Esmeraldas region (Eisenberg et al., 2006). The timber and oil palm industries built secondary and tertiary roads throughout the 1990s and into the 2000s to facilitate the transport of lumber and production and processing of palm oil within the region (Sierra, 1999); as a byproduct, connectivity between communities has increased (Eisenberg et al., 2006). The study population is located primarily in Eloy Alfaro, one of seven Esmeraldas *cantones*. The village of Borbón (~ 5,000 inhabitants), a major population center of the region, serves as a regional outpost for the exchange of goods and services due to its location at the confluence of the Cayapas, Santiago, and Onzole rivers. In addition to Borbón, thirty-one smaller villages in Eloy Alfaro and San Lorenzo *cantones* were selected over time and enrolled in the study using block randomization to ensure that there were communities in the study which: 1) resided on each of the three rivers basins as well along the newly-constructed road, and 2) on varying distances from the commercial center, Borbón (Eisenberg et al., 2006). The main analyses presented include 28 of the 31 villages. Three villages populated primarily by an indigenous group, the Chachi, were excluded due to limited data over the study time period. Qualitative data collection also showed extensive dietary differences between the Chachi and the Afro-Ecuadorian and Mestizo peoples living in other villages (unpublished). For further details on enrollment see Supplement 1.

Data Collection

This study uses secondary data from a natural experiment (Eisenberg et al., 2006) that examined the impact of new roads on diarrheal disease between 2003 and 2013 (Supplement 1 provides information on numbers of villages, households, and individuals included as well as the dates, as well as the dates of when data were collected, referred to as study cycles). Consequently, proximal determinants of nutritional status, such as dietary intake or physical activity, were not available for analysis. Cycles 3-11 (2004-2013) are included in this study. During each study cycle, we took anthropometry and hemoglobin measurements for all children < 5 who were enrolled in the study (see Supplement 2 for methods for these measurements). Because nutrition was of secondary interest to the original study objectives, we began collecting the anthropometry and hemoglobin data the beginning of Cycle 3. Data on village-, family-, and individual-level sociodemographic data were also obtained. Data collection methods and study procedures were approved by the University of Michigan and the Trinity College Institutional Review Boards and the Universidad San Francisco de Quito Bioethics Committee.

Definitions

The primary nutrition outcomes are prevalence of stunting, wasting, underweight, anemia, overweight, and obesity among children aged 0-59 months. Anthropometric measurements were converted to Z-scores using the WHO's 2006 Child Growth Standards (WHO, 2006) and the igrowup Macro Version 3.2.2 for SAS, modified to reflect a recumbent length cutpoint of 12 months. Stunting, an index of chronic undernutrition, is measured as height-for-age Z-scores < -2 (WHO, 2006). Wasting, an index of acute undernutrition, is measured as weight-for-height Z-scores < -2 (WHO, 2006). Underweight, a composite measure of chronic and acute undernutrition, and overweight/obesity are general measures of nutrition and are measured using weight-for-age Z-score < -2 and body-mass-index-for-age Z-score > 2 or 3, respectively (WHO, 2006). As described in Supplement 2, observations with extreme Z-scores as calculated by the macro were excluded. Anemia was defined as hemoglobin concentrations less than 11.0g/dl in children from 6-59 months and undefined for children <6 months

(Peña-Rosas et al., 2011). Of note, this crude measure of anemia does not distinguish between its different causes.

The primary exposure is remoteness, a static, continuous, village-level measure calculated from the cost and time it took to travel to Borbón by road or river in 2003. For each village, travel time and total cost of travel to Borbón were recorded by field staff members. For each village *i*, rank of remoteness, R_i, was then calculated by standardizing values of time, T_i, and cost, C_i separately (i.e., dividing by the sum of all times and costs across the 28 villages respectively) and then summing the two terms. Because the metric is the result of two values standardized to a [0,1] scale, the possible range of R_i is from 0 (the town Borbón itself) to 2 (the theoretical farthest community from Borbón). Categorical forms of the remoteness scale, previously developed (Eisenberg et al., 2006), were used for descriptive purposes only, whereas whenever remoteness was included as a predictor in a regression model, the continuous remoteness metric was used. This continuous measure was normalized to range from 0 to 1 so as to aid in interpretation of the model results (i.e., a one unit increase in remoteness score reflects comparing the least remote community to the most remote community). Comparing the extremes of this scale, all villages in the close remoteness category also had road access in 2013; likewise, with the exception of one community that remains isolated due to the cost and time of travel required to reach it, none of the villages in the far remoteness category had road access at the end of the study period. We suggest that this gradient of remoteness was maintained during the ten years of data collection (Kraay et al., in press). A more complete description of the remoteness metric and community characteristics is provided elsewhere (Eisenberg et al., 2006).

As described by both local individuals and reports from non-profits, decisions regarding where to build roads within the study site were independent of community characteristics. They were instead based on extracting valuable timber or gold, or building extensive palm oil plantations (Jiménez et al., 2011; García Salazar, 2001). Additionally, government reports show that road development in the province (MTOP, 2011; SENPLADES, 2013) primarily focused on highway construction outside of the study region. This suggests that road locations, and thus the resulting remoteness measure, may be thought of as essentially randomly assigned to village, and is therefore probabilistically unassociated with community characteristics in the pre-road era. We assume a baseline (i.e. pre-road) level of balance between villages on their community socioeconomic status and therefore interpret post-road differences in socioeconomic status across villages as driven by road access: the introduction of a road catalyzes changes to community profiles, which in turn influence child nutritional status. That is, we interpret socioeconomic status variables as mediators rather than confounders in this analysis. This logic is empirically supported by a prior study in the region showing that communities with road access indeed experienced greater monetary benefits after road construction (Sierra, 1999). Increased household wealth may change the types of foods a household will consume, affecting the nutritional status of children.

Three variables were selected for mediation analysis based on their significance in the literature and predicted trends by remoteness: wealth, education, and family size (Walker et al., 2007). Household wealth was examined using a previously-developed and validated score based on house and roof materials (Supplement 3) (Arias et al., 1996). A higher score is a proxy indicator for higher wealth. Education was defined as the highest level of education in years achieved by any individual within a household. Family size was measured by the number of non-working children (under the age of thirteen) in each household. We present a village-level analysis; thus, individual-level covariates are not including within the modeling.

Analysis plan

The relationship between remoteness and our binary nutrition outcomes was assessed using logistic generalized estimating equations (GEE) models to account for within-individual correlations over time using an autoregressive of order 1 (AR1) correlation structure. The AR1 correlation structure assumes the correlation between observations declines exponentially as a function of the distance in time. For example, an AR1 process with parameter 0.5 would correspond to correlations of 0.5, 0.25, and 0.125 between observations made 1, 2, and 3 time points apart, respectively. We argue that residual within-village dependencies are largely captured by remoteness and so are not explicitly modeled. Similarly, within-household dependencies would very likely result from the household-level measures included, and so are not explicitly modeled.

The primary analyses were separate logistic GEE models for each nutritional outcome, with remoteness and cycle as the predictors. To compare early cycles (3-7) to later cycles (8-11), an additional stratified model was run to assess occurrence of temporal changes. Because the communities enrolled in the study overtime changed at the study midpoint, as stated in Supplement 1, analysis was conducted on villages without two consecutive cycles of missing data. Comparing the covariates and remoteness category between excluded and included villages, the mean and standard deviation for each of the variables is similar, with the exception of *Maximum Education* (see Supplement 4 for a further discussion). Following the initial logistic regression modeling, additional explorations of an outcome variable were undertaken only if there was a significant association between remoteness and the nutritional outcome variable. For the reduced set of outcome variables, six co-variates were individually added to the model: Household-level covariates for wealth, education, and family size and the village-level mean value for these three household-level variables. This resulted in six unique models (for each outcome variable) that were each compared to the unadjusted model to assess for mediation via a change in the *beta*-coefficient for remoteness. As a crude proxy for mediation, if upon comparison the adjustment resulted in a 10 percent change in the *beta*-coefficient for remoteness towards the null, the covariate in the model was considered to partially explain the remoteness-nutrition relationship. A separate analysis stratifying the prevalence of each nutritional outcome by ethnicity in cycles 7-11 is included in Supplement 5. All analyses were performed using SAS version 9.3 (SAS Institute, Cary NC).

RESULTS

A total of 4030 weight measurements and 4029 height measurements were taken on 2350 children during the study period; Supplement 2 presents the number of measurements excluded from the analysis for each nutritional outcome.

Characteristics of the final study population at time of enrollment are presented in Table 1. Of the household-level socioeconomic covariates, there is little difference in the mean and standard deviation by remoteness category at time of enrollment, supporting our conceptual framework. Moreover, there is also little difference in the mean and frequency of and individual child characteristics across remoteness categories, providing evidence that further statistical models should not include these variables as co-variates.

Of the estimated undernutrition outcomes, the aggregate prevalence of stunting and anemia were 12 (95% CI=11%; 13%) and 55 percent (95% CI=53%; 56%), respectively, over the entire study period; whereas the prevalence of wasting and underweight during the study period was similar at 6 percent (95% CI for wasting=5.3%; 6.7% and 95% CI underweight=5.4%; 6.9%). The prevalence of overweight children was 5 percent whereas the prevalence of obesity was 1.6 percent throughout the entire study (see Supplement 6 for age-stratified estimates of all nutrition outcomes). The prevalence of each nutritional outcome over time is presented in Figure 1. As noted in the figure, the prevalence of stunting decreased over the study period, and although not statistically significant, child obesity increased. The outlying high prevalence of wasting for cycle 3 and the outlying low prevalence of anemia in cycle 7, were likely due to wide variation in the number of villages included in the cycle. Further examination of the cycle 3 peak in wasting prevalence showed five communities driving the aggregate prevalence. Exploratory analyses of anthropometric measures within these outlying communities suggest that length/height measurements may have been subject to non-systematic measurement error where height measurements in children were likely biased towards higher values in cycle 3, exaggerating the aggregate wasting prevalence at this time point. Nevertheless, trends in the prevalence of wasting and anemia were not significant as other cycles varied minimally across time.

Logistic regression models adjusting for cycle, a proxy measure of time, showed that the odds of stunting decreased significantly as a function of remoteness (Table 2). This was also demonstrated in Figure 2, a graph comparing the change in prevalence of stunting in far and close villages over time, smoothed from a predicted generalized additive model with 3 knots (i.e., the number of sections that the dataset have been divided into for the smoothing process). Similar to stunting, the odds of anemia were lower in the more remote villages compared to the less remote villages, adjusted for cycle. There was no significant difference in the odds of the other four nutritional outcomes. Although there was a point estimate decrease, the OR of stunting between more versus less remote villages did not vary significantly over time. The relationship between remoteness and odds of anemia was also similar throughout the study.

Using a cut-point of 10 percent change in estimate criterion, inclusion of the household wealth score in the stunting model showed minimal impact on the pathway from remoteness to stunting (Table 3), suggesting, paradoxically, that wealth score may not explain differences observed by remoteness. When maximum education level in the household is included in the model, the directionality of the 25 percent change in the *beta*-coefficient of remoteness suggests that educational attainment may play a role as a mediating factor in the pathway between remoteness and stunting. The influence of household family size, however, was null. Incorporation of community-level covariates within the models to account for within-village correlations did not meaningfully change the *beta*-coefficient of remoteness in the stunting model. An examination of the role of household-level variables as mediators in the relationship between remoteness and anemia was not possible due to the large number of missing covariates and GEE assumptions that data should be missing at random.

DISCUSSION

The odds of stunting and the odds of anemia were lower in more remote villages than in closer villages (OR = 0.43 and 0.56 respectively; Table 2). This result was not explained by household size and may be partially explained by wealth and education (Table 3). This observed spatial gradient was preserved throughout the study period (2003-2013; Figure 2) even though stunting decreased over time throughout the study region (from 14% to 11%; Figure 1). This observed relationship between remoteness and stunting and remoteness and anemia is not unexpected; the World Bank found an association between stunting and anemia in Ecuadorian children, suggesting a likely shared etiology (Walker et al., 2007). We hypothesize that if remoteness has an impact on either stunting or anemia through a shared causal pathway, there will be an impact on both nutritional outcomes.

Roads can influence the nutritional status of child through numerous pathways. We frame our results here within a discussion of the pathways connecting roads to child stunting that are mediated by market access, wealth and education. Road construction tends to distribute health services, wealth, and risk of disease unequally (Frenk et al., 1984) among villages in the area. Thus, comparing nutritional outcomes across remoteness categories provides insight into the macro-level determinants influencing nutritional outcomes in rural Esmeraldas. Various studies have observed that closer proximity to roads and/or population centers with markets is associated with higher levels of diversity in diets, which likely contributes to more nutritionally adequate diets (Sibhatu et al., 2015; Kumar et al., 2015). Yet, the nutritional implications of greater road access will almost certainly vary based on the quality, diversity, and seasonality of food items available at newly accessible markets, regional price-to-wage ratios, and existing nutritional deficiencies or excesses (Jones, 2016). If markets do not provide access to affordable, healthy food options, their influence on nutrition outcomes may be negligible or even negative. Houck et al. (2013), in an 8-year study among children and adolescents in indigenous villages in the Northern Ecuadorian Amazon (Houck et al., 2013), found a higher prevalence of stunting among children and youth living in communities with increased market activity compared to another village with stable market activity. As a parallel, we suggest that the stable exposure to market activities likely experienced in close villages may partially explain the faster reduction in stunting among children living in villages close to a road. Whereas, the presence of a stable protein source from fish in the far villages can explain the lower stunting prevalence relative to the road villages; and a subsequent steady increased exposure to market activities over time can explain the observed slower reduction in stunting. Overall, these results highlight the important role of the differing pace of economic development within villages in our study, which in turn propagates changes to dietary patterns or income generation via exposure to market activities.

We hypothesize that road construction, a marker of economic development, may influence nutrition outcomes through changing resource availability. Specifically, we found evidence suggesting educational attainment acts as a mediator between road access and child health outcomes, a finding consistent with social epidemiologic literature framing parental education as a social determinant of health (Li et al., 2009). Interestingly, the association between remoteness and stunting increased in magnitude when wealth was included in the models. This result suggests that perhaps unmeasured confounding between the household-level covariates and nutritional outcomes is obscuring the indirect mediation pathway (VanderWeele, 2010).

In addition to the impact of road access on nutritional status we found that the prevalence of wasting is of medium severity for a population per the WHO recommendations (WHO, 2006), while more than half of children in the study site have a hemoglobin level less than 11 g/dl and are classified as having anemia (6% and 55% prevalence, respectively). The prevalence estimates of underweight, overweight, obesity, and stunted children fall beneath the WHO cut point for population health concern. Nevertheless, the prevalence of stunting is five times higher than what would be expected based on the WHO recommended standards. Although the public health concern related to wasting, anemia and stunting among young children may be more pressing given the larger number of individuals affected, the prevalence of overweight children may also be of concern given its rising prevalence. The prevalence of child overweight in this population is five percent. This is slightly lower than, but near to the global prevalence of child overweight which recently stood at approximately seven percent. This prevalence of child overweight, and the increasing trend associated with it, has been highlighted as a key public health concern in LMI countries (Black et al., 2013). We also observed a more than three-fold increase in the prevalence of obesity over time. Although the absolute levels are small, these data suggest that obesity within the region should be monitored. More data are need to assess whether the increasing trend of overweight translates to high levels of obesity in adults, which would suggest a dual burden of malnutrition in the population. Prior studies have observed a double burden of undernutrition and excess bodyweight at the population level in Ecuador (Freire et al., 2014) as well as elsewhere in the region, namely Brazil, Colombia, Guatemala, Mexico, and Uruguay (Rivera et al., 2014).

Most studies examining malnutrition among preschool age children in Latin America focus on nutritional outcomes and proximal determinates rather than distal, macro-level determinants of child well-being. Our study is unique but has limitations. First, our conceptual model requires an assumption that locations were balanced in the pre-road era in terms of village-level socioeconomic status. In this way, we effectively view remoteness as a randomly assigned “treatment”, whose effects are mediated through subsequent changes in village-level socioeconomic status. This assumption is consistent with information indicating that areas were chosen for road construction without regard to their socioeconomic status. However, as with any randomly assigned treatment, imbalances can arise purely through chance, and we are unable to rule out that possibility because we do not have pre-road data. Prior literature has concluded that the introduction of a road does increase the socioeconomic status characteristics of a village (Sierra, 1999), suggesting that the results found here are consistent with the hypothesized conceptual model. Additionally, there are also limitations inherent in using the odds ratio to assess common outcomes. Consequently, our models in Table 3 may overestimate the size of association in the mediation analysis and inhibit the comparison between indirect and direct effects due to issues of collapsibility (Zhang et al., 1998; Greenland et al, 1999; VanderWeele et al., 2010). While future work is required to address and understand these limitations, our study is a first step in identifying the relationship between road access and child nutritional status.

This works presents the effects of an economic development project on child nutritional status over space and time. We found that road expansion influenced child stunting and anemia in the Esmeraldas region of northern coastal Ecuador up to a decade after the main road was completed. These child malnutrition outcomes differ by road access, with children living in more remote communities experiencing a lower prevalence of malnutrition. Additional research is required to identify the dietary and lifestyle changes that have occurred in the last ten years. This study, however, is a first approach to identifying the distal determinants of nutritional change, which is necessary for developing appropriate interventions to counter the negative outcomes of road construction.

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Table 1. Characteristics of the Total Study Population and of Population Stratified by Remoteness Category at Enrollment into the Study (N=1257 households and 2350 individuals). Mean (SD) is reported for age, and frequency is reported for sex (% males) and ethnic group (% Afro-Ecuadorian). Mean (SD) is reported for children per household, wealth score, and maximum education.

Covariate	**Study Population**		**Remoteness Category**			
			Borbón	**Close**	**Medium**	**Far**
Child Characteristics		***Number of Children***				
Age (months)	24 (17)	2350	28 (16)	24 (16)	24 (17)	24 (17)
Male	49%	2333	48%	48%	50%	49%
Afro-Ecuadorian[a]	80%	1980	46%	79%	76%	89%
Total children	-	2350	242	950	342	816
Household Characteristics		***Number of Households***				
Children per household	2.3 (1.5)	1170	3.0 (1.5)	2.2 (1.4)	2.1 (1.3)	2.3 (1.6)
Maximum Education (years)[b]	7.4 (3.9)	658	9.4 (3.9)	6.6 (3.8)	6.8 (3.5)	7.4 (3.7)
Wealth Score	4.6 (1.1)	964	[c]	4.7 (1.1)	4.5 (1.1)	4.5 (1.1)
Total households	-	1275	173	509	189	404

[a] Ethnic group missing for children enrolled in cycle 11 of data collection and includes 370 missing observations

[b] Maximum Education missing for 617 households

[c] Household construction data not collected Borbón

Table 2. Odds Ratio for each Predictor in the Model Assessing the Association Between Remoteness and Nutritional Outcome ($\text{outcome} = \beta 0 + \beta 1(\text{remoteness}) + \beta_i(\text{cycle}_i)$). The OR for continuous remoteness, which ranges from 0 to 1 (as defined in the text), reflects a statistical comparison between the two extremes of all the remoteness values observed in the dataset. Fifteen villages were included in the analysis, villages were excluded if they were missing >2 cycles of data or 2 consecutive cycles of data.

Model Results for Entire Study Period

	Stunting		**Wasting**		**Underweight**		**Anemia**		**Overweight**		**Obesity**	
	OR (95% CL)	***P-value***	***OR (95% CL)***	***P-value***	***OR (95% CL)***	***P-value***	***OR (95% CL)***	***P-value***	***OR (95% CL)***	***P-value***	***OR (95% CL)***	***P-value***
Remoteness	0.43 (0.30-0.63)	<0.0001	1.3 (0.84-1.9)	0.26	0.81 (0.51-1.3)	0.39	0.56 (0.44-0.70)	<0.0001	1.1 (0.68-1.7)	0.64	1.6 (0.68-3.8)	0.28
Cycle 3	1.4 (1.0-2.1)	0.06	5.4 (3.0-9.6)	<0.0001	1.4 (0.85-2.3)	0.19	0.86 (0.62-1.2)	0.40	0.71 (0.39-1.29)	0.26	0.17 (0.04-0.74)	0.02
Cycle 4	2.5 (1.2-3.8)	0.01	0.30- (0.3-3.6)	0.34	1.1 (0.48-2.5)	0.84	1.1 (0.66-1.9)	0.67	0.85 (0.33-2.19)	0.74	0.50 (0.07-3.6)	0.49
Cycle 5	1.5 (1.0-2.2)	0.06	0.93 (0.43-2.0)	0.85	1.1 (0.65-1.9)	0.69	0.64 (0.45-0.90)	0.01	0.46 (0.22-0.98)	0.04	0.10 (0.01-0.81)	0.03
Cycle 7	0.97 (0.60-1.6)	0.89	0.66 (0.25-1.8)	0.41	0.69 (0.37-1.3)	0.25	0.21 (0.13-0.32)	<0.0001	0.45 (0.17-1.2)	0.10	0.34 (0.07-1.6)	0.18
Cycle 8	1.2 (0.75-1.8)	0.52	2.3 (1.2-4.4)	0.02	0.87 (0.49-1.5)	0.62	0.88 (0.61-1.2)	0.47	0.68 (0.35-1.3)	0.26	0.82 (0.31-2.2)	0.69
Cycle 9	0.85 (0.55-1.3)	0.47	2.3 (1.2-4.3)	0.01	1.4 (0.82-2.2)	0.24	1.3 (0.89-1.8)	0.19	0.84 (0.46-1.6)	0.58	0.42 (0.13-1.4)	0.16
Cycle 10	0.88 (0.59-1.3)	0.52	1.2 (01.64-2.4)	0.53	0.76 (0.46-1.2)	0.29	0.93 (0.67-1.3)	0.68	0.48 (0.51-1.4)	0.50	0.52 (0.2-1.4)	0.18
Cycle 11*	1	-	1	-	1	-	1	-	1	-	1	-

Stratified Model at Mid-Point of Data Collection

	Stunting		**Wasting**		**Underweight**		**Anemia**		**Overweight**		**Obesity**	
Cycles 3-7	***OR (95% CL)***	***P-value***	***OR (95% CL)***	***P-value***	***OR (95% CL)***	***P-value***	***OR (95% CL)***	***P-value***	***OR (95% CL)***	***P-value***	***OR (95% CL)***	***P-value***
Remoteness	0.39 (0.23-0.66)	0.001	1.5 (0.90-2.7)	0.12	0.63 (0.32-1.3)	0.19	0.56 (0.39-0.79)	0.001	1.8 (0.69-4.9)	0.22	10 (0.56-185)	0.12
Cycle 3	1.5 (0.94-2.5)	0.09	8.1 (3.2-20)	<0.0001	2.3 (1.2-4.4)	0.01	4.3 (2.9-6.4)	<0.0001	1.3 (0.54-3.2)	0.55	0.33 (0.06-1.9)	0.21

Cycle 4	2.2 (1.1-4.3)	0.02	0.55 (0..06-4.7)	0.58	1.8 (0.76-4.0)	0.19	6.0 (3.4-11)	<0.0001	1.5 (0.47-5.1)	0.48	0.89 (0.08-9.5)	0.92
Cycle 5	1.5 (0.98-2.4)	0.06	1.3 (0.43-3.8)	0.65	1.8 (0.98-3.2)	0.06	3.2 (2.2-4.7)	<0.0001	0.85 (0.29-2.5)	0.7734	0.20 (0.02-2.2)	0.19
Cycle 7*	1	-	1	-	1	-	1	-	1	-	1	-
Cycles 8-11												
Remoteness	0.49 (0.30-0.80)	0.004	0.97 (0.53-1.8)	0.92	1.0 (0.54-1.9)	1.0	0.55 (0.40-0.75)	0.0002	0.91 (0.50-1.7)	0.77	1.2 (0.49-3.1)	0.66
Cycle 8	1.2 (0.76-1.8)	0.47	2.4 (1.2-4.6)	0.01	0.92 (0.51-1.6)	0.77	0.89 (0.62-1.3)	0.51	0.71 (0.37-1.4)	0.3	0.83 (0.32-2.1)	0.71
Cycle 9	0.86 (0.59-1.3)	0.49	2.3 (1.2-4.4)	0.01	1.4 (0.82-2.2)	0.24	1.3 (0.89-1.8)	0.19	0.86 (0.46-1.6)	0.62	0.43 (0.13-1.5)	0.17
Cycle 10	0.87 (0.59-1.3)	0.50	1.2 (0.65-2.4)	0.51	0.75 (0.46-1.2)	0.26	0.93 (0.66-1.3)	0.68	0.85 (0.51-1.4)	0.53	0.53 (0.21-1.4)	0.20
Cycle 11*	1	-	1	-	1	-	1	-	1	-	1	-

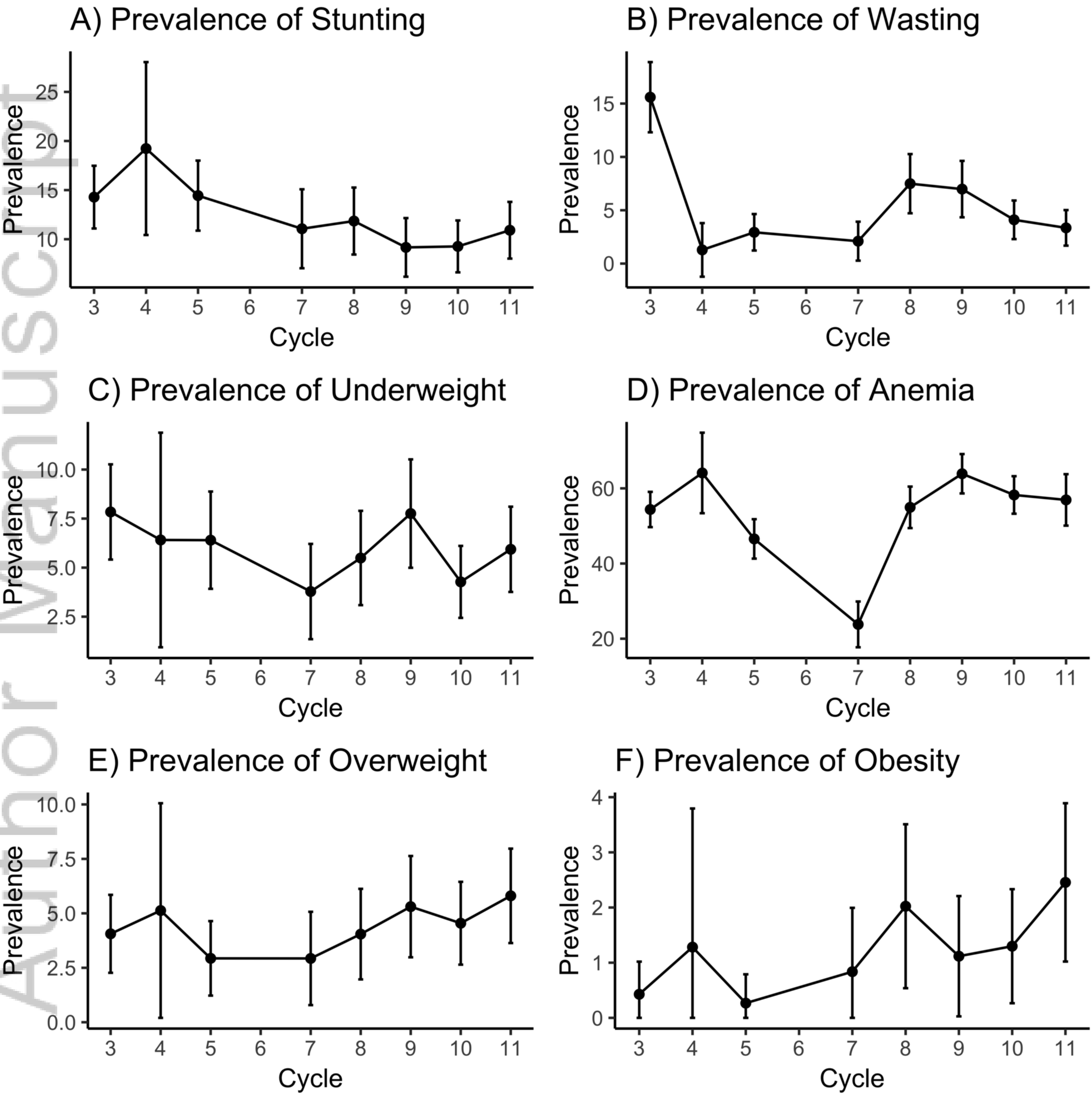
**referent group*

Table 3. Mediation analysis of Covariates within the Remoteness-Stunting Pathway. Beta coefficient represents stunting between the most remote villages and the least remote villages, adjusted for time and select covariates. Percent change in beta upon addition of each covariate is displayed, where a positive Δ beta represents a shift away from the null, and a negative Δ beta value represents a shift towards the null. GEE model is outcome = $\beta_0 + \beta_1$(remoteness) + β_2(cycle) + β_3(covariate)

	Wealth Score	**Maximum Education**	**Children per household**
Adjustment for Household-Level Mediators	***Beta***	***Beta***	***Beta***
Remoteness Estimate in Unadjusted Model	-0.83	-0.83	-0.83
Remoteness Estimate in Household-Level Adjusted Model	-0.92	-0.63	-0.85
% Δ	*10%*	*-25%*	*1.5%*
Adjustment for Community-Level Mediators	***Beta***	***Beta***	***Beta***
Remoteness Estimate in Unadjusted Model	-0.83	-0.83	-0.83
Remoteness Estimate in Community-Level Adjusted Model	-0.86	-0.84	-0.85
% Δ	*3.4%*	*1.1%*	*1.7%*

Figure 1. Prevalence of each nutritional outcome across time in 15 villages. Thirteen villages not included because they were missing data in >2 cycles or were missing two consecutive cycles. Data collected within cycles during: 3) November 2004 - June 2005, 4) August 2005 - February 2006, 5) June 2006 - December 2006, 7) September 2007 - October 2008, 8) December 2008 - November 2009, 9) January 2010 - December 2010, 10) January 2011 - May 2012, and 11) July 2012 – July 2013. The prevalence of stunting and the prevalence of anemia significantly decreased based on the GEE model: outcome = $\beta_0 + \beta_1$(cycle). All other outcomes did not have statistically significant trends over time.

Figure 2. Prevalence of stunting, smoothed with a generalized additive model containing 3 knots, across time for remoteness categories of villages that were included in GEE model.



A) Prevalence of Stunting

B) Prevalence of Wasting

C) Prevalence of Underweight

D) Prevalence of Anemia

E) Prevalence of Overweight

F) Prevalence of Obesity

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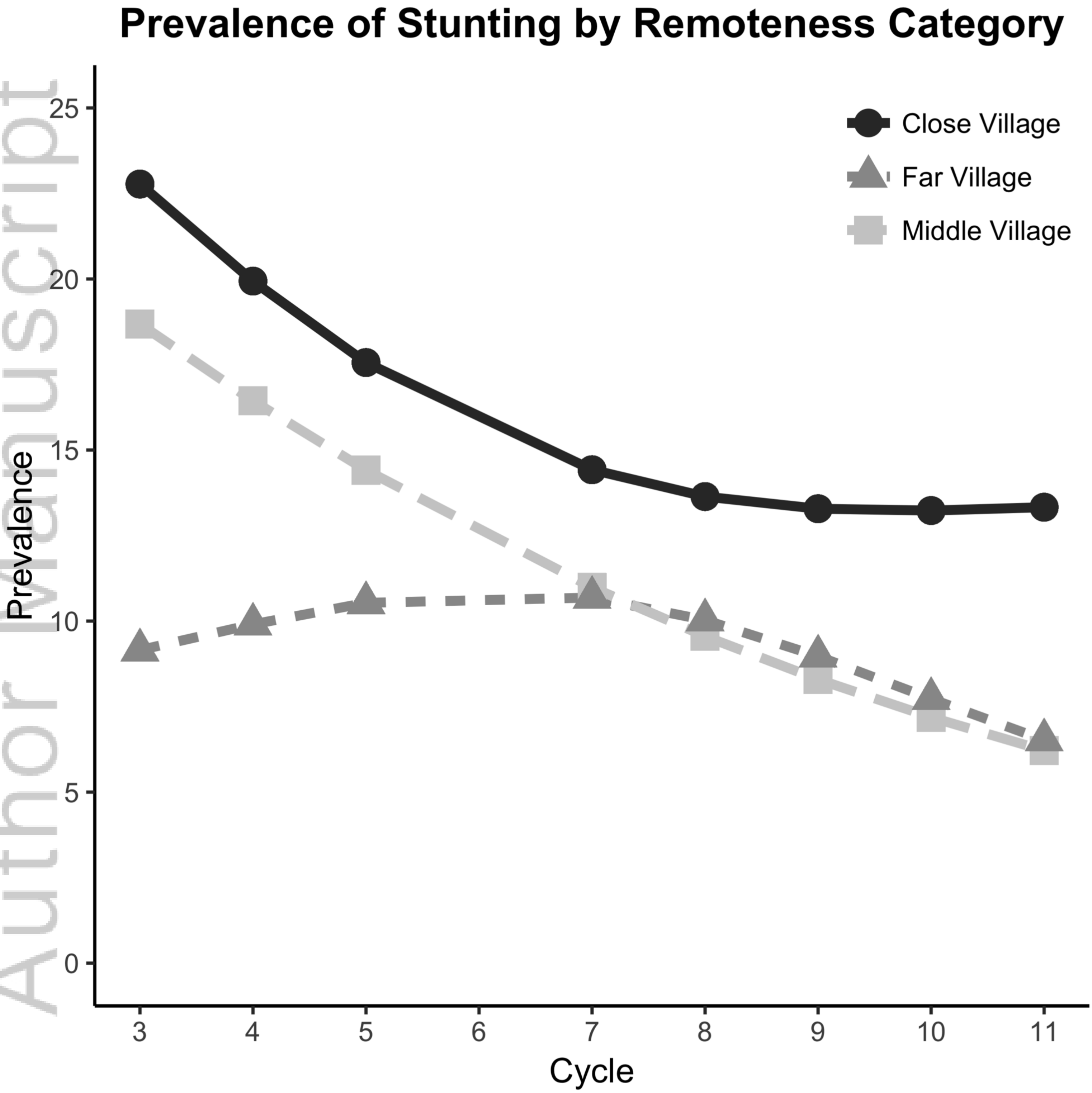

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